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A study of non-neutral networks

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Abstract: Hahn and Wallsten [3] wrote that net neutrality "usually means that broadband service providers charge consumers only once for Internet access, do not favor one content provider over another, and do not charge content providers for sending information over broadband lines to end users." In this paper we study the implications of being non-neutral, particularly by charging the content providers. Using game theoretic tools, we show that by adding the option for the service providers to charge the content providers, not only may the content providers and the internauts suffer, but also the access provider's performance degrades.

Key-words: Net neutrality, mathematical models.

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Étude des réseaux non-neutres

Résumé : Dans cet article, nous examinons les conséquences de règles de facturation violant la troisième clause de la définition de neutralité du réseau selon Hahn et Wallsten [3]: "les fournisseurs de connectivité haut débit ne facturent qu'une seule fois les utilisateurs pour l'accès à l'Internet, ne favorisent pas un fournisseur de contenu par rapport à un autre, et *ne facturent pas les fournisseurs de contenu pour envoyer de l'information aux utilisateurs via les réseaux à large bande*." Nous montrons, à l'aide d'outils de la théorie des jeux, que la possibilité de procéder à une telle facturation peut nuire, non seulement aux fournisseurs de contenu et aux utilisateurs, mais aussi aux fournisseurs de connectivité eux-même.

Mots-clés : Neutralité du réseaux, modèles mathématiques.

1 Introduction

Network neutrality is an approach to providing network access without unfair discrimination among applications, content, nor the specific source of traffic. What is discrimination and what is fair discrimination? If there are two applications or two services or two providers that require the same network resources and one is offered better quality of service (shorter delays, higher transmission capacity, etc.) then there is a discrimination. When is a discrimination "fair"[1]? A preferential treatment of traffic is considered fair as long as the preference is left for the user[2]. Internet service providers (ISPs) may have interest in discrimination either for technological problems or for economic reasons. Traffic congestion has been a central argument for the need to discriminate traffic (for technological reasons) and moreover, for not practicing network neutrality, in particular to deal with high-volume peer-to-peer traffic. However, many ISPs have been blocked or throttled p2p traffic independently of congestion conditions.

There may be many hypothetical ways to violate the principle of network neutrality. Hahn and Wallsten wrote that network neutrality "usually means that broadband service providers charge consumers only once for Internet access, do not favor one content provider over another, and do not charge content providers for sending information over broadband lines to end users." (p. 1 of [3]) We therefore restrict our attention in this paper to the practices of these types of network neutrality.

That net neutrality acts as a disincentive for capacity expansion of their networks, is an argument recently raised by ISPs. In [1] the validity of this claim was checked. Their main conclusion is that under net neutrality the ISPs invest to reach the social optimal level, while under-or-over investing is the result when net neutrality is dropped. In this case, ISPs stand as winners, while content providers (CP) move to a worst position. Users that rely on services that have paid the ISPs for preferential treatment will be better off, while the rest of the users will have a significantly worse service.

ISPs often justify charging content providers by their need to cover large and expensive amount of network resources. This is in particular relevant in the 3G

[1]The recent decision on Comcast v. the FCC was expected by the general public to deal with the subject of "fair" traffic discrimination, as the FCC ordered Comcast to stop interfering with subscribers traffic generated by peer-to-peer networking applications. The Court of Appeals for the District of Columbia Circuit was asked to review this order by Comcast, arguing not only on the necessity of managing scarce network resources, but also on the non-existent jurisdiction of the FCC over network management practices. The Court decided that the FCC did not have express statutory authority over the subject, neither demonstrated that its action was "reasonably ancillary to the ... effective performance of its statutorily mandated responsibilities". The FCC was deemed, then, unable to sanction discrimatory practices on Internet's traffic carried out by american ISPs, and the underlying case on the "fairness" of their discriminatory practices was not even discussed.

[2]Nonetheless, users are just one of many actors in the net neutrality debate, which has been enliven throughout the world by several public consultations on new legislation on the subject. The first one, proposed in the USA (expired on 26/04/2010), was looking for the best means of preserving a free and open Internet. The second one, carried out in France (finishing 17/05/2010), asks for the different points of view over net neutrality. A third one is intended to be presented by the UE in the summer of 2010, looking for a balance on the parties concerned as users are entitled to an access the services they want, while ISPs and CPs should have the right incentives and opportunities to keep investing, competing and innovating. See [9, 2, 8].

wireless networks where huge investments were required for getting licenses for the use of radio frequencies. On the other hand, the content offered by a CP may be the most important source of the demand for Internet access; thus, the benefits of the access providers are due in part to the content of the CPs. It thus seems "fair" that benefits that ISP make of that demand would be shard by the CPs.

We find this notion of fair sharing of reveneus between economic actors in the heart of cooperative game theory. In particular, the Shapley value approach for splitting reveneus is based on several axioms and the latter fairness is on of them. Many references have advocated the use of the Shapley value approach for sharing the profits between the providers, see, *e.g.*, [5, 6]. We note however that the same reasoning used to support payments by access providers to content providers (in the context of can be used in the opposite direction. Indeed, many CPs receive third party income such as advertising revenue thanks to the user demand (eyeballs) that they create. Therefore, using a Shapley value approach would require content providers to help pay for the network access that is necessary to create this new income.

The goal of this paper is to study the impact of such side payments between providers on the utilities of all actors. More precisely, we study implications of one provider being at a dominating position so as to impose payments from the other one[3]. We examine these questions in this paper using simple game theoretic tools. We show how side payments may be harmful for all parties involved (users and providers).

Another way to favor a provider over another one is to enforce a leader-follower relation to determine pricing actions. We show how this too can be harmful for all.

2 Basic model: three collective actors and usage-based pricing

We consider the following simple model of three actors,

- the internauts (users) collectively,
- a network access provider for the internauts, collectively called ISP1, and
- a content provider and its ISP, collectively called CP2.

In this section, the two providers are assumed peers; leader-follower dynamics are considered in Section 4 below. The internauts pay for service/content that requires both providers. Assume that they pay $p_i \geq 0$ to provider i (CP2 being $i = 2$ and ISP1 being $i = 1$) and that their demand is given by

$$D = D_0 - pd$$

where

$$p = p_1 + p_2 \geq 0, \ \ D \geq 0.$$

[3]In the European Union, such dominating positions in the telecommunications markets are controlled by the article 14, paragraph 3 of the Directive 2009/140/EC, considering the application of remedies to prevent the leverage of a large market power over a secondary market closely related.

So, provider i's revenues are

$$U_i = Dp_i, \quad i = 1, 2.$$

2.1 Collaboration

The total price that the providers can obtain if they cooperate is maximized at $p_i = D_0/(4d)$. The total revenue per provider is then $U_i^{max} = D_0^2/(8d)$. The demand is then $D_0/2$.

2.2 Fair competition

If the providers do not cooperate then the utility of provider i is obtained by computing the Nash equilibrium. We get:

$$\frac{\partial U_i}{\partial p_i} = D - p_i d = 0, \ i = 1, 2. \tag{1}$$

This gives $p_1 = p_2 = D_0/(3d)$. The demand is now $D_0/3$, larger than in the cooperative case, and the revenue of each provider is $D_0^2/9$, less than before.

Next consider the competitive model and assume we install *side payments*: CP2 is requested to pay p_3 to ISP1 for "transit" costs. So, the revenues of the providers are:

$$\begin{aligned} U_1 &= [D_0 - (p_1 + p_2) \cdot d]\,(p_1 + p_3) \\ U_2 &= [D_0 - (p_1 + p_2) \cdot d]\,(p_2 - p_3) \end{aligned}$$

As the model so far is symmetric, we can in fact allow for negative value of p_3 which would model payment from the ISP1 to CP2 instead, *e.g.*, payment for copyright, as discussed below.

2.3 Discussion of side payments

At this point we render it asymmetric by assuming that p_3 is determined by ISP1 for the case $p_3 > 0$, *i.e.* additional transit revenue from the content provider in a "two sided" payment model to ISP1 [4, 7]. Then, unless $D = 0$ there is no optimal p_3: as it increases, so does U_1. Thus, at equilibrium necessarily $D = 0$, and the revenues of both service and content providers are 0. Hence p_1 and p_2 sum up to D_0/d. Then by decreasing p_1 slightly, the demand will become strictly positive, so ISP1 can increase its utility by U_1 without bound by choosing p_3 sufficiently large. Therefore, at equilibrium $p_1 = 0$ and $p_2 = D_0/d$. If $p_2 > p_3$ then by a slight decrease in p_2, U_2 strictly increases so this is not equilibrium. We conclude that at equilibrium, $p_3 \geq p_2$. To summarize, the set of equilibria is given by $\{p_1 = 0, p_2 = D_0/d \text{ and } p_3 \geq D_0/d\}$.

Thus by discriminating one provider over the other and letting it charge the other provider, both providers lose. Obviously the internauts do not gain anything either, as their demand is zero!

We have considered above side payment from the CP2 to ISP1. In practice, the side payment may go in the other direction. Indeed, there is a growing literature that argues that ISP1 has to pay to CP2. This conclusion is based on cooperative game theory (and in particular on Shapley values) which stipulates that if the presence of an economic actor A in a coalition creates revenue to another actor B, then actor A ought to be paid proportionally to the benefits that its presence in the coalition created. In our case, the CP2 creates a demand of users who need Internet access, and without the CP2, ISP1 would have less subscribers.

The use of Shapley value (and of a coalition game approach, rather than of a non-cooperative approach) has the advantage of achieving Pareto optimality. In particular this means that the total revenue for ISP1 and CP2 would be those computed under the cooperative approach.

Side payment to the CP2 from ISP1 may also represent payment to the copyright holders of the content being downloaded by the internauts. In particular, a new law is proposed in France, by a member of parliament of the governing party, to allow download of unauthorized copyright content and in return be charged *proportionally* to the volume of the download, with an average payment of about five euros per month. A similar law had been already proposed and rejected five years ago by the opposition in France. It suggested to apply a tax of about five euros on those who wish to be authorized to download copyrighted content. In contrast, the previously proposed laws received the support of the trade union of musicians in France. If these laws were accepted, the service providers would have been requested to collect the tax (that would be paid by the internauts as part of their subscription contract). Note that although $p_3 < 0$ in our model could represent these types of side payments, the copyright payments per user are actually not decision variables.

3 Revenue generated by advertising

We now go back to the basic collaborative model to consider the case where the CP2 has an additional source of revenue from advertisement that amounts to $p_4 D$. p_4 is assumed in this paper to be a constant. The total income of the providers is

$$\Pi = (D_0 - pd)(p + p_4) \tag{2}$$

Then

$$\frac{\partial \Pi}{\partial p} = D_0 - 2pd - dp_4 \tag{3}$$

Equating to zero, we obtain

$$p = \frac{D_0 - p_4 d}{2d} \tag{4}$$

The total demand is $(D_0 + p_4 d)/2$, and the total revenues at equilibrium are

$$U_t^{\max} = \frac{D_0^2 + 2\, d\, p_4\, D_0 + d^2\, p_4^2}{4\, d} \tag{5}$$

This result does not depend on the way the revenue from the internauts is split between the providers.

3.1 The case where $p_2 = 0$

In particular, the previous result covers the case where $p_2 = 0$, *i.e.*, the case where advertising is the only source of revenue for the content provider CP2.

One may consider this to be the business model of the collective consisting of (i) BitTorrent permanent seeders and (ii) specialized torrent file resolvers (*e.g.*, Pirate Bay).

Note that BitTorrent permanent seeders may be *indifferent* to downloading to BitTorrent leecher clients (particularly during periods of time when the seeder workstations are not otherwise being used) because of flat-rate pricing for network access, *i.e.*, a flat-rate based on capacity without associated usage-based costs (not even as overages).

3.2 Best response

The utilities for the network access provider ISP1 and the content provider CP2 are, respectively,

$$U_1 = [D_0 - (p_1 + p_2) \cdot d]\,(p_1 + p_3) \tag{6}$$

and

$$U_2 = [D_0 - (p_1 + p_2) \cdot d]\,(p_2 - p_3 + p_4). \tag{7}$$

We first show that for any p_2, it is optimal for the ISP1 to choose $p_1 = 0$. First consider the problem of the best choice of p_1 and p_3 assuming the quantity $p_1 + p_3$ is constant; clearly, U_1 strictly decreases in p_1 so that a best response cannot have $p_1 > 0$.

Thus, if p_2 is not controlled (in particular if $p_2 = 0$ so that CP2's only revenue is from a third party and not directly from the users), then ISP1 would gain more by charging the CP2 than by charging the users. This is also consistent with the simple fact that $\partial U_1/\partial p_3 \;\geq\; \partial U_1/\partial p_1$.

3.3 Nash equilibrium

With $p_1 = 0$ and $p_3 \geq 0$, the utility of ISP1 is

$$U_1 = [D_0 - p_2 d]\,p_3 \tag{8}$$

Thus the condition on the best response of ISP1 for a given p_2 gives $p_2 = D_0/d$, *i.e.*, the demand is zero. On the other hand, for this p_2 to be a best response for U_2, $p_3 = p_2 + p_4$. We conclude that there is a unique Nash equilibrium given by $p_1 = 0$, $p_2 = D_0/d$, and $p_3 = D_0/d + p_4$.

4 Stackelberg equilibrium

Stackelberg equilibrium corresponds to another aspect of asymmetric competition, in which one competitor is a leader and the other a follower. Actions are no longer taken independently: here, first the leader takes an action, and then the follower reacts to this action.

Let's restrict to $p_3 \geq 0$.

We assume that the ISP1 is the leader. Given p_1 and p_3, U_2 is concave in p_2. So, a necessary and sufficient condition for p_2 to maximize this is

$$\frac{\partial U_2}{\partial p_2} = D_0 - d \cdot (p_2 - p_3 + p_4) - d \cdot (p_1 + p_2) = 0 \tag{9}$$

holds with equality for $p_2 > 0$. That is, to maximize U_2,

$$p_2 = \frac{1}{2}\Big(\frac{D_0}{d} + p_3 - p_1 - p_4\Big) \ > 0. \tag{10}$$

Substituting p_2 in U_1, we obtain:

$$\begin{aligned} U_1 &= [D_0 - (p_1 + p_2) \cdot d]\,(p_1 + p_3) \\ &= \frac{1}{2}\,[D_0 - 3p_1 d - p_3 d + p_4 d]\,(p_1 + p_3) \end{aligned}$$

We now compute the actions that maximize the utility U_1 which is concave in (p_1, p_3). We have

$$\frac{\partial U_1}{\partial p_1} = \frac{D_0 - 4dp_3 - 6dp_1 + dp_4}{2} \leq 0 \tag{11}$$

$$\frac{\partial U_1}{\partial p_3} = \frac{D_0 - 2dp_3 - 4dp_1 + dp_4}{2} \leq 0 \tag{12}$$

For $p_1 > 0$, (11) should hold as equality. Subtracting (11) from (12) we get $p_3 \leq -p_1$, and hence they are zero. This conclusion is in contradiction with our assumption $p_1 > 0$.

Assume that $p_1 = 0$ and $p_3 > 0$. Then U_1 is concave in p_3 and (12) holds with equality. Hence

$$p_3 = \frac{D_0}{2d} + \frac{p_4}{2} \tag{13}$$

maximizes U_1. Substituting in (10) we get

$$p_2 = \frac{1}{4}\Big(\frac{3D_0}{d} - p_4\Big) \tag{14}$$

We conclude that if $p_4 d < 3D_0$ Then the Nash equilibrium is $p_1 = 0$, and p_3 and p_2 are given, respectively, by (13) and (14).

Since we assume here that $p_2 \geq 0$, then in case $p_4 d \geq 3D_0$, we will have $p_2 = 0$ since this value maximizes (14).

5 Conclusions and on-going work

Using a simple, parsimonious model of linearly diminishing user/consumer demand as a function of price, we studied a game between collective players, the user ISP and content provider, under a variety of scenarios including: non-neutral two-sided transit pricing, copyright payments made by the ISP, the effects of flat-rate pricing, advertising revenue, cooperation, and leadership. In particular, we demonstrated under what conditions non-neutral transit pricing of content providers may result in revenue loss for all parties in play (*i.e.*, so that at least one player opts out of the game, where all players are necessary for positive outcome).

In on-going work, we are considering issues of non-monetary value and copyright. Moreover, we are including the users as active players. Finally, we are considering the effects of content-specific (not *application* neutral) pricing.

References

[1] K. Cheng, S. Bandyopadhyay, and H. Gon, "The debate on net neutrality: A policy perspective", *Information Systems Research*, June 2008. Available at SSRN: `http://ssrn.com/abstract=959944`.

[2] "Consultation publique sur la neutralité du net," du 9 avril au 17 mai 2010.

[3] R. Hahn and S. Wallsten, "The Economics of Net Neutrality", *Economists' Voice*, The Berkeley Economic Press, **3**(6), pp. 1-7, 2006.

[4] P. Hande, M. Chiang, R. Calderbank, and S. Rangan. "Network pricing and rate allocation with content provider participation", in *Proc. IEEE INFOCOM*, 2009.

[5] R.T.B. Ma, D.-M. Chiu, J.C.S. Lui, V. Misra, and D. Rubenstein, "Interconnecting eyeballs to content: A Shapley value perspective on ISP peering and settlement", in *Proc. Int'l Workshop on Economics of Networked Systems (NetEcon)*, pp. 61-66, 2008.

[6] R.T.B. Ma, D.-M. Chiu, J.C.S. Lui, V. Misra, and D. Rubenstein, "On cooperative settlement between content, transit and eyeball internet service providers", in *Proc. ACM Int'l Conference on Emerging Networking EXperiments and Technologies (CoNEXT)*, 2008.

[7] J. Musacchio, G. Schwartz and J. Walrand, "A two-sided market analysis of provider investment incentives with an application to the net-neutrality issue", *Review of Network Economics*, **8**(1), 2009.

[8] "Neelie Kroes vice president of the european commission commissioner for the digital agenda." *Press release RAPID*, April 2010.

[9] "Notice of proposed rulemaking (FCC 09/93)," October 2009–April 2010.

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